SHORT-PERIOD SURFACE-WAVE DISPERSION FROM AMBIENT NOISE TOMOGRAPHY IN WESTERN CHINA

Michael H. Ritzwoller[1], Yingjie Yang[1], and Michael E. Pasyanos[2]

University of Colorado at Boulder[1], Lawrence Livermore National Laboratory[2], and China Earthquake Administration [3]

ABSTRACT

The goal of ambient noise tomography (ANT) is to improve the calibration of surface-wave propagation in aseismic areas, especially at periods shorter than 20 sec, which are hard to obtain from earthquake surface waves. In earlier work, we improved and optimized the method of ambient noise surface wave tomography for systematic application and applied it to broad-band seismic data obtained in Europe and the western part of the Middle East. The resulting phase and group speed measurements were documented in Ritzwoller et al. (2007).

Current work concentrates on the application of ANT in central Asia, especially western China, where significant data resources are available. The data are taken from about 180 broad-band seismic stations including the permanent Federation of Digital Seismographic Network (FDSN), two regional networks (KZ and KN), and three temporary US PASSCAL installations in and around China: HIMNT (YL), Namche Barwa (XE), and MIT-CHINA (YA). Cross-correlations are computed in daily segments and then stacked over a three-year period (2002-2004). Rayleigh wave phase and group speed dispersion curves from 8 sec to 60 sec period are measured using a phase-matched filter, frequency-time analysis technique. The dispersion measurements from our data set are combined with those from Zheng et al. (2008) (using the China National Seismic Network) to perform ambient noise tomography. The resulting group and phase velocity maps demonstrate significant correlation with known geologic features, such as sedimentary basins and lateral variation of crustal thickness.

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **SEP 2008**	2. REPORT TYPE	3. DATES COVERED **00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE **Short-Period Surface-Wave Dispersion from Ambient Noise Tomography in Western china**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Lawrence Livermore National Laboratory,PO Box 808,Livermore,CA,94551-0808**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Proceedings of the 30th Monitoring Research Review: Ground-Based Nuclear Explosion? Monitoring?Technologies, 23-25 Sep 2008, Portsmouth, VA sponsored by the National Nuclear Security Administration (NNSA) and the Air Force Research Laboratory (AFRL)

14. ABSTRACT
see repotr

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**9**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

OBJECTIVES

The goal of this research is to obtain surface-wave dispersion measurements based on cross-correlations of ambient seismic noise and to produce a new data set of inter-station phase and group velocity measurements in Central Asia, especially western China, to complement that of Zheng et al. (2008), using the China National Seismic network. These new dispersion data are used to produce improved group and phase velocity tomographic maps, particularly at short periods (< 20 sec), which can provide new constraints on crustal structures.

RESEARCH ACCOMPLISHED

Introduction

In earlier work, we developed a new method to approach the surface-wave path calibration problem based on the use of long records of ambient seismic noise. This method, which we call "ambient noise tomography," is based on the ability to estimate surface-wave Green functions by cross-correlating long sequences of ambient seismic noise (Shapiro and Campillo 2004; Shapiro et al., 2005). The details of this method are documented in Bensen et al. (2007). Dispersion measurements made on the estimated Green functions present significant advantages over traditional measurements made on recordings of waves emanated from earthquakes. Ambient noise tomography is particularly useful in calibrating surface-wave path effects at periods below 20 sec.

Previously, we applied this method to the large broad-band data set that has emerged through the growing Virtual European Broadband Seismic Network and regional networks in Europe and the western part of the Middle East (Yang et al., 2007; Richmond et al, 2007). Here, we shift our focus to Central Asia, where significant data resources are available. Under previous DOE/NNSA and Air Force support, we devoted substantial efforts toward developing Rayleigh and Love wave group speed data sets and tomographic maps at short and intermediate periods from earthquake data across Central Asia. These data sets have been widely distributed and used by the US nuclear monitoring community. Due to its substantial intra-continental seismicity, which results from the continental collision between India and Asia, Central Asia is particularly suited for classical earthquake surface-wave tomography (e.g., Ritzwoller and Levshin, 1998; Ritzwoller et al., 1998). However, at periods below about 20 sec, path coverage is suboptimal, and geographically variable, and the quality of the dispersion measurements degrades to appreciably shorter periods compared with longer periods.

Ambient noise tomography improves path coverage and resolution, especially at periods below 20 sec across much of Central Asia with the available data resources. We have processed all the available data sources in 2002, 2003, and 2004 in Central Asia and obtained inter-station surface-wave dispersion measurements. The new data set improves the path calibration of short-period surface waves.

Data and Method

In Central Asia, between 2002 and 2004, there were significant data resources available, including the permanent FDSN, two regional networks, the Kazakh network (KZ) and Kyrgyz network (KN), and three temporary US

PASSCAL installations in and around China. The FDSN, regional networks, and PASSCAL data are all openly available now at the IRIS/DMC. The locations of the stations used in this study are shown in Figure 1. The names and the operation times of all FDSN station, regional network, and PASSCAL experiments are listed in Table 1. Any experiment that overlaps with another experiment in operation time is marked with a cross. These overlaps guarantee that dense path coverage in this study can be generated, as shown in Figure 1. Cross-correlations are run in each of the three years (2002–2004). The cross-correlations include those between stations within individual experiments and those across experiments and permanent installations. Letting $\leftrightarrow$ represent cross-correlation, we can depict the data processing symbolically as follows: FDSN$\leftrightarrow$FDSN, PASSCAL$\leftrightarrow$FDSN, and PASSCAL$\leftrightarrow$ PASSCAL.

The data processing procedure applied here is similar to that described by Bensen et al. (2007) at great length. Continuous data are pre-processed before cross-correlation and stacking, which includes removal of instrument response, temporal normalization, and spectral whitening. The purpose of time normalization is to suppress the influence of earthquake signals, which is particularly important in the seismically active region of Central Asian. Cross-correlations are performed daily in the broad period band from 5 to 100 sec and then stacked over all time periods (three years). The correlation function contains both positive and negative time lags, resulting from noise propagating from the two opposite directions between a pair of stations. We use the symmetric component of the correlation as the empirical Green function (EFG) by averaging the positive and negative parts of the correlation. Examples of broad-band (5 to 30 sec) symmetric-component cross-correlations between a common station, LSA (Lhasa, China), and other stations are shown in Figure 2.

To evaluate the quality of cross-correlations, we calculate the signal-to-noise ratio (SNR) for each cross-correlation. If the SNR is larger than 15, Rayleigh wave group and phase speeds are then measured using a frequency-time analysis (Ritzwoller and Levshin, 1998; Lin et al, 2008). The inter-station dispersion measurements from cross-correlations are used to invert for the Rayleigh wave phase and group velocity maps using the method of Barmin et al. (2001).

Ambient Noise Surface-Wave Tomography

Zheng et al. (2008) performed ambient noise tomography in China using data from the China National Seismic Network. They obtained inter-station Rayleigh wave dispersion measurements between the 48 Chinese backbone stations at periods from 8 to 60 sec. Because most of the 48 stations are located in eastern China, the path coverage in western China is relatively sparse. To increase the density of path coverage and improve the resolution of tomography in western China, we combine the dispersion measurements from our data set with those from Zheng et al. (2008) to perform ambient noise surface-wave tomography. The tomography is performed for both phase and group speeds on a $1^{o} \times 1^{o}$ grid across western China and surrounding regions using the tomographic method of Barmin et al. (2001). Resolution is estimated simultaneously using the method described by Barmin et al. (2001) with modifications presented by Levshin et al. (2005). An example of path coverage and resolution is shown in Figure 3 for the 20-sec measurements. Results are similar for other periods.

Examples of resulting phase and group speed maps at two periods of 12 and 30 sec are shown in Figure 4. For comparison, maps of sedimentary and crustal thicknesses are plotted at the bottom of Figure 4. At the short periods (< 15 sec), surface waves are dominantly sensitive to shear velocities in the upper crust. Because the shear velocity of sediments is low, short-period low velocity anomalies are a good indicator of sedimentary basins. In the 12-sec Rayleigh wave speed maps, low velocities are correlated well with the locations of major basins, including the Tarim Basin, Qaidam Basin, Sichuan Basin, and Ordos Basin. At the intermediate periods of this study (25–60 sec), Rayleigh waves are primarily sensitive to crustal thickness and the shear velocities in the middle crust, lower crust, and uppermost mantle. At these periods, low velocities are usually observed in a region with thicker crust. In the 30-sec Rayleigh wave speed maps, low velocity is observed across Tibet where the crust is very thick (Figure 4f). Higher velocity is imaged in regions to the north and east of Tibet. The boundary between fast and slow velocities nearly coincides with the sharp topographic change.

CONCLUSIONS

In this study, we use ambient noise data recorded at about 180 broad-band seismic stations, including the permanent FDSN, two regional networks (KZ and KN), and three temporary US PASSCAL installations in and around China: HIMNT (YL), Namche Barwa (XE), and MIT-CHINA (YA). Group and phase velocity dispersion measurements between stations are obtained at periods from 8 sec to 60 sec. These dispersion measurements are combined with those from Zheng et al. (2008) taken from the 48 stations of the China National Seismic Network to perform ambient noise tomography. The resulting velocity maps provide an improvement in the understanding of surface-wave dispersion in Central Asia, particularly at periods below about 20 sec. The group and phase velocity maps agree well with known geologic features, such as sedimentary basins and the lateral variation of crustal thickness.

ACKNOWLEDGMENTS

REFERENCES

Barmin, M., M. Ritzwoller, and A. Levshin (2001). A fast and reliable method for surface wave tomography, *Pure Appl. Geophys.* 158: (8), 1351–1375.

Bensen, G. D., M. H. Ritzwoller, M. P. Barmin, A. L. Levshin, F. Lin, M. P. Moschetti, N. M. Shapiro, and Y. Yang (2007). Processing seismic ambient noise data to obtain reliable broad-band surface wave dispersion measurements, *Geophys. J. Int.* 169: 1239–1260.

Levshin, A.L., M.P. Barmin, M.H. Ritzwoller, and J. Trampert (2005). Minor-arc and major-arc global surface wave diffraction tomography, *Phys. Earth Planet. Ints.* 149: 205–223.

Lin, F., M.P. Moschetti, and M.H. Ritzwoller (2008). Surface wave tomography of the western United States from ambient seismic noise: Rayleigh and Love wave phase velocity maps, *Geophys. J. Int.*, doi:10.1111/j1365-246X.2008.03720.x.

Richmond, R, Ritzwoller, M. H., Villasenor, A., Yang, Y, Beck, S.L., Lerner-Lam, A, Levin, V., Shapiro, N.M, (2007). Ambient Noise Surface Wave Tomography Across Europe, AGU FALL MEETING, San Francisco, Dec. 10–14.

Ritzwoller, M., Y. Yang, R. Richmond, M. Pasyanos, A. Villasenor, V. Levin, A. Hofstetter, V. Pinsky, N. Kraeva, and A. Lerner-Lam (2007). Short period surface wave dispersion across the Mediterranean Region: improvements using regional seismic networks, in *Proceedings of the 29th Monitoring Research Review: Ground-Based Nuclear Explosion Monitoring Technologies,* LA-UR-07-5613, Vol. 1, pp. 226–235.

Ritzwoller, M. H. and A. L. Levshin (1998). Eurasian surface wave tomography: Group velocities, *J. Geophys. Res.*, 103: 4839–4878.

Ritzwoller, M. H., A. L. Levshin, L. I. Ratnikova, and A. A. Egorkin (1998). Intermediate period group velocity maps across Central Asia, Western China, and parts of the Middle East, *Geophys. J. Int.* 134: 315–328.

Shapiro, N. M., M. Campillo, L. Stehly, and M. H. Ritzwoller (2005). High-resolution surface-wave tomographyfrom ambient seismic noise, *Science* 307: 1615–1618.

Shapiro, N., and M. Campillo (2004). Emergence of broadband Rayleigh waves from correlations of the ambient seismic noise, *Geophys. Res. Lett.* 31: (7), 1615–1619.

Yang, Y., M. Ritzwoller, A. Levshin, and N. Shapiro (2007). Ambient noise Rayleigh wave tomography across Europe, *Geophys. J. Int.* 168 (1): 259–274.

Zheng, S., X. Sun, X. Song, Y. Yang, and M. H. Ritzwoller (2008). Surface wave tomography of China from ambient seismic noise correlation, *Geochem. Geophys. Geosyst.* 9: Q0502, doi:10.1029/2008GC001981.

Table 1. Broadband seismic networks used in this study during 2002-2004. The network names are shown in rows and columns with the same order. A crossed block indicates the two networks overlap in time; i.e. inter-network cross-correlations can be performed.

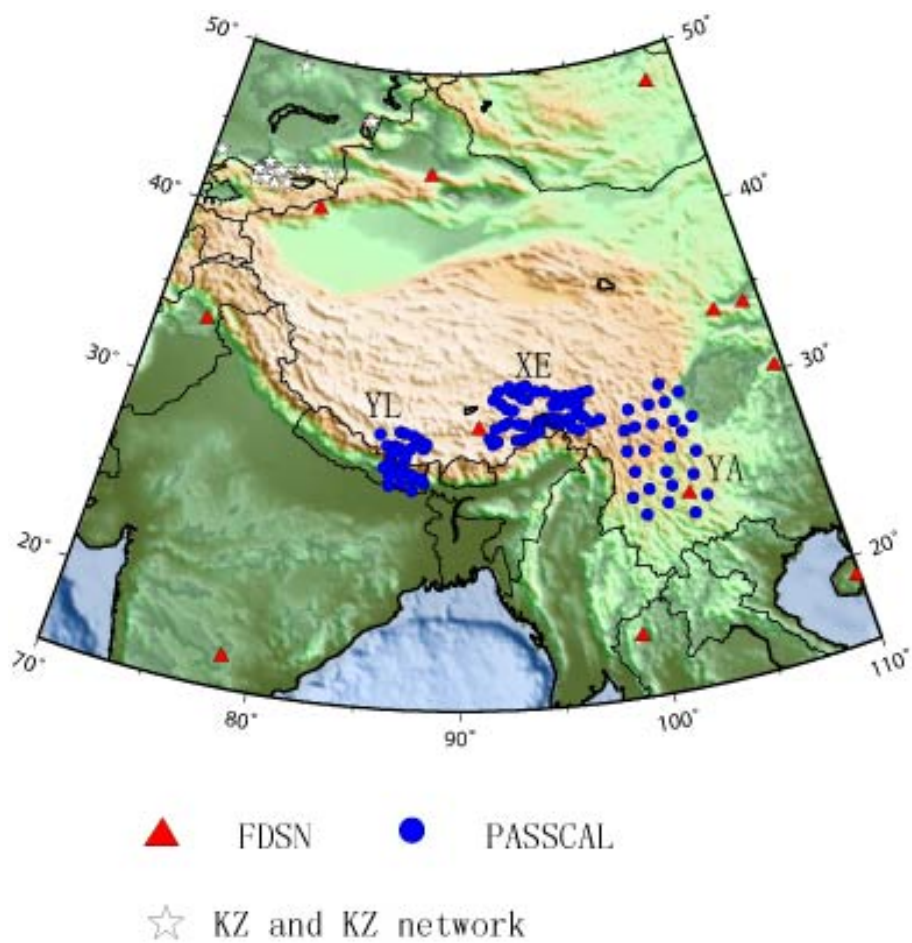| Network (network Code) (appr. Operation time)	XW	YL	XE	YA	FDSN
HIMNT (YL) (Sep 2001-Dec 2002)		✕			✕
Namche Barwa (XE) (Jul 2003-Dec 2004)			✕	✕	✕
MIT-China (YA) (Sep 2003-Dec 2004)				✕	✕
FDSN and Regional (G,PS,IC,II,IU,KZ,KN)					✕

Figure 1. Station distributions in W. China and surrounding regions. Stations include international stations (FDSN), regional networks (KZ and KN) and PASSCAL experiments (from west to east: YL, HIMNT; XE, Namche Barwa; YA, MIT-CHINA).
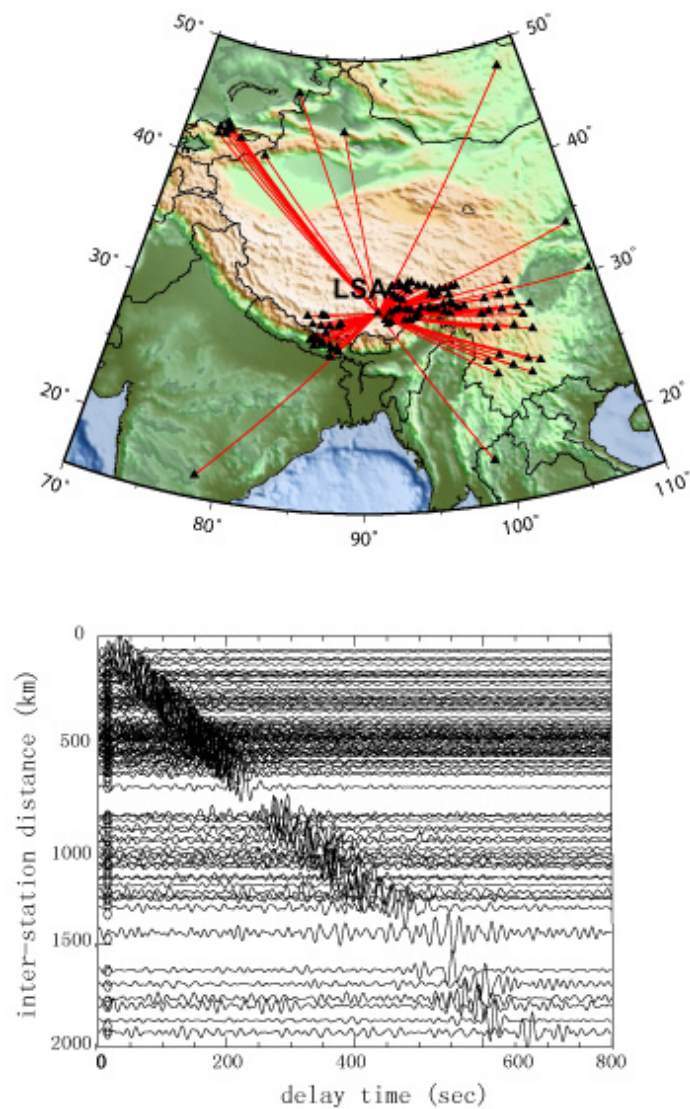
Figure 2: An example of a cross-correlation record-section with inter-station paths plotted in the top diagram for cross-correlation with SNR > 15. The result is centered on station LSA (Lhasa, China) for the symmetric-signals, band-pass filtered from 10 to 30 sec.
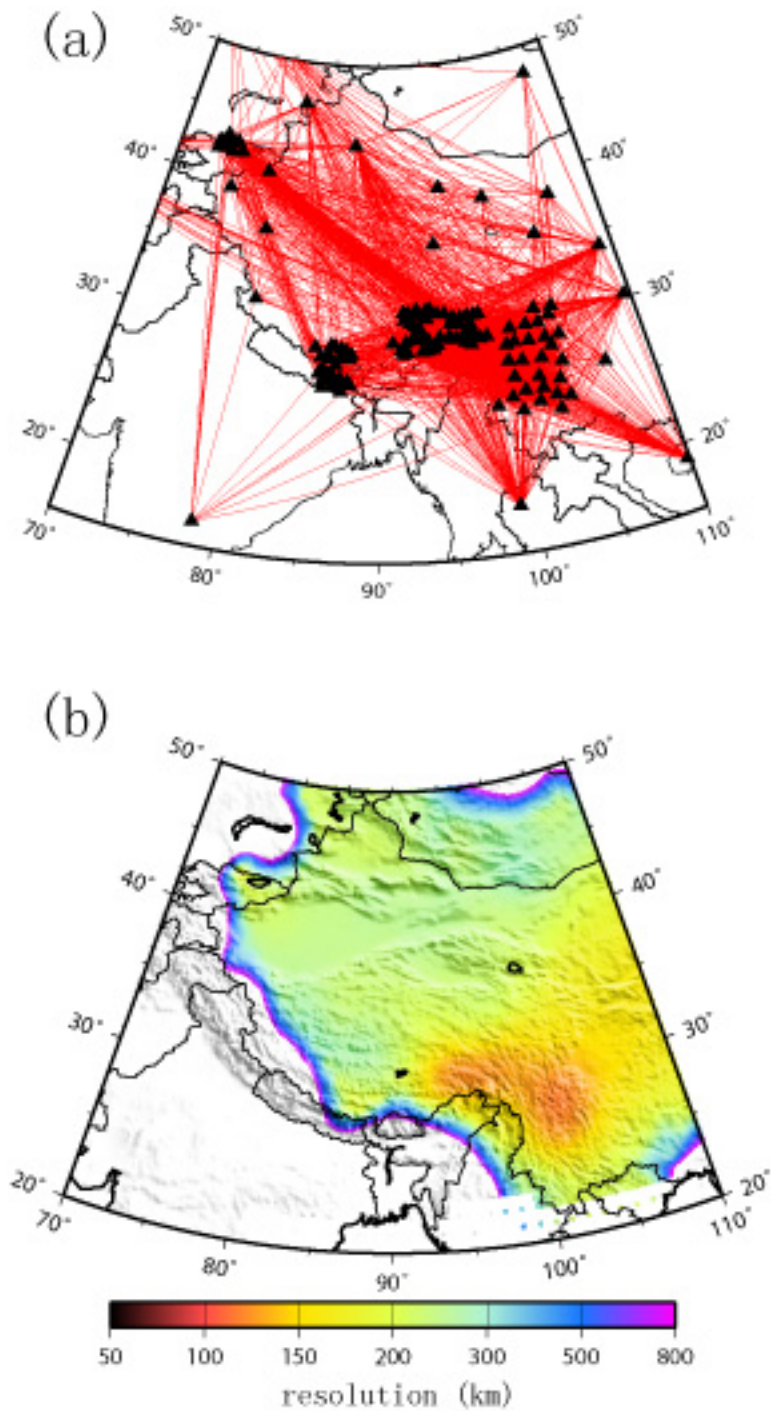
Figure 3. (a) Path coverage and (b) resolution estimated for 20 sec period. Resolution is defined as the standard deviation of 2-D Gaussian fit to the resolution surface at each model node.
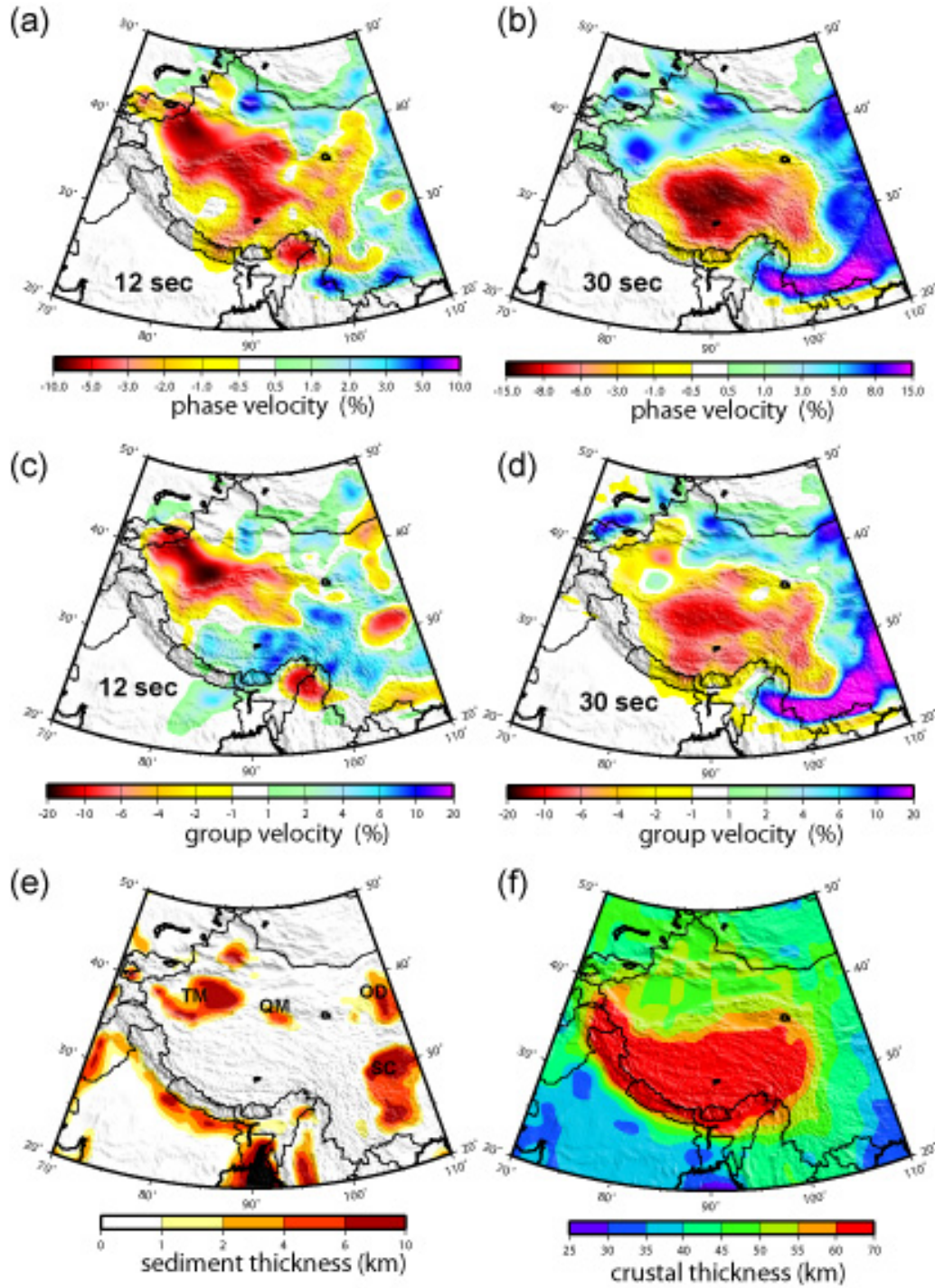
Figure 4. (a-d) Rayleigh wave phase (top) and group (middle) velocity maps at 12 and 30 sec periods. The velocities are plotted as perturbation relative to the average values. (e) and (f) Maps of sediment thickness and crustal thickness (Laske and Masters, 1997). The major sedimentary basins are labeled: Tarim (TM), Daidam (QM), Sichuan (SC), and Ordos (OD).